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"Planetary Seismological Studies"

Final Report

June 19, 1975

National Aeronautics and

Space Administration

Grant No. NGR 05-002-316

Table of Contents

Preface

This report is a compilation of continuing thought concerning seismic experiments on future Mars exploration missions, and the instrumentation required for their performances.

Recent advances in micro-computer techniques have expanded the scope of possibilities by making feasible the processing of data prior to transmission to earth; discussion of these techniques and experience with the Viking hardware and software as related to future experiments comprise a major portion of this report. Sensor techniques have been previously reported and are mentioned only briefly here, though comparisons are included.

The report consists of several sections as follows:

I. Summary of a Mars Viking Seismic Experiment

II. Instrument Characteristics

III. Implementation

IV. Appendices

V. References

FIGURES

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I. Summary of the Mars Viking Seismic Experiment

A. Scientific Objectives and Design Strategy

The main objective of the Advanced Viking Seismic Experiment will be to map the internal structure of the planet Mars. The Mariner missions have given us a strong indication that Mars is a recently tectonically active planet. Prior to Mariner we suspected that Mars might be intermediate to the Earth and the Moon in its geological and geophysical processes. The Moon is currently an essentially dead planet as far as seismic activity is concerned. This is consistent with its ancient surface, the age of its rocks and the mild stresses which are presently being supported by its interior. This state is also consistent with thermal history calculations. Mars, in addition to the evidence for recent volcanism and tectonism, has a very rough gravity field. This in turn implies high stresses in the interior. One could even make a case from the Mariner photographs that plate tectonics is beginning to develop on Mars. The line up of volcanoes near 110° occurs near a continental margin and exhibits the geometry of island arc areas on Earth. Nix Olympica seems to be the analog of the Hawaiian Islands and may be a Martian hot spot. The equatorial valley could be a rift zone, modified by erosion. Thermal history calculations indicate that the thermal evolution of Mars will start later than either the Earth or the Moon. There is also some evidence for polar wandering on Mars.

The first order questions regarding the internal structure of Mars are: (1) what is the thickness of the mantle, (2) what is the composition of the mantle, (3) what is the size and composition of the core and (4) what is the three dimensional distribution of Marsquakes? These can all be answered with a long-lived landed seismic experiment. If the seismometer has a long period capability, i.e. the ability to measure surface waves and free oscillations, a single large Marsquake can provide a comprehensive view of the interior. Because of the probable high wind noise on Mars and the probable high frequency background noise of the lander, including random high frequency pulses and because of the optimism we now have regarding the tectonic activity of the planet, we consider it essential that a long-period (low-frequency) capability be part of the Advanced Viking Seismic Experiment.

It should be stressed that a Marsquake large enough to excite free oscillations or globe encircling surface waves provides information about the internal structure and the density distribution and this information can be interpreted independently of knowledge regarding the location and time of the event. The fundamental spheroidal, radial, and toroidal modes of the Earth have periods of 54, 21, and 43 minutes, respectively. These are excited only by the largest terrestrial earthquakes. These long periods are difficult to measure and require instruments such as quartz or laser strainmeters, gravimeters or displacement sensitive seismometers. The corresponding modes on Mars have periods of 20, 12, and 26 minutes. The shorter periods are due to the smaller size of the planet. Actually, the existence of a core and the structure of the mantle and crust can be establishd without measuring the gravest fundamental modes. A credible Martian free oscillation experiment could be performed with an instrument that is sensitive to periods shorter than 600 seconds.

We still have no information regarding the spectra of short period (body wave) signals or noise. Thus the design of the short period part of the seismometer must include provisions to change the response after landing. This can easily be accomplished.

In addition to increasing the bandwidth, the Advanced Viking Seismometer differs from the Viking Seismometer in having a larger dynamic range, a higher sensitivity and better timing. Wind and lander induced noises are still expected to be the major problem. In order to unambiguously identify these disturbances the seismic package should include a wind speed-direction sensor which records on the same time base as the seismometer, and strain gage or accelerometer devices which can identify lander related noises.

The other main objective of the seismic experiment is to map the seismicity of the planet and to correlate seismic activity with geology and topography. This can be adequately handled with two landers and Viking instrumentation with better timing, higher sensitivity and more positive techniques of isolating spurious signals.

B. Type of Signals That May Exist

Several types of signals can be expected to exist. First, there will be the microseismic background which is generated by wind and pressure variations and thermal effects. This is considered "noise" on the earth because it is of little intrinsic interest to the seismologist. On Mars the real "noise" will include, also, disturbances of, or in, the landed vehicle. The important signals will be caused by events such as faulting and volcanic activity, which write quite a different signature than the previous types of signals. Also, on Mars there may be a significant number of meteoritic impacts recorded. Some of these may be indistinguishable from quake events but, due to certain unique characteristics of impact signals, it may be possible to segregate some of these from quake signals. In any case, they will be useful sources to map the internal structure of Mars.

C. Requirements of the Instrumentation

To achieve the scientific goals it is necessary to have a system which indicates the relative amplitude and direction of ground motion in three axes. Ordinarily the instrument components are arranged in an orthogonal pattern (N,E,Z) though other configurations are sometimes used.

Since the event envelopes normally exhibit considerable amplitude modulation with the arrival of waves of different type and paths, and since these arrivals are used in interpretation, a time scale is necessary. It is desirable not to have excessive amplitude distortion or clipping, which might disguise the wave groups; thus a large dynamic range with reasonable linearity is a requirement.

The sensitivity of the system must be such that small events can be detected, since if Marsquakes occur in a distribution similar to earthquakes the number will be approximately in inverse proportion to their magnitude.

It is advantageous to have some means of scanning frequency content of both discrete events and the microseismic and noise signals.

Caltech has previously designed a system for Viking '76 which is adequate for a first sampling of the Martian seismic environment. It is hoped that this instrumentation will provide data which can help select the design parameters of more sophisticated instruments to extend this knowledge, and that experience gained in design of the previous experiment will benefit the development of more advanced seismic experiments for future missions. Recent advances in electronics make it possible to partially redesign the instrumental response on the surface of Mars without a prohibitive weight penalty, and at the same time extend the frequency range that can be observed.

The Viking '76 instrumentation includes a 3 component short period system of moderate sensitivity having provision for basic spectrum analysis of microseismic background by selectable filtering, a triggered mode at accelerated data rate for event registration, and data compaction (see Ref. 1) to provide for full-time operation without exceeding the data bit allotment. Weight volume and power constraints are extreme. Presumably advanced Viking missions will permit weight, volume, and power consumption in excess of the allowances on Viking '76; this in combination with recent technology advances will permit the design of more sophisticated instrumentation. With knowledge of ground motion amplitudes and frequencies, noise signals, etc., expected to be derived from Viking '76, it will be possible to design systems having longer period and broad band response which will be compatible with the signal environment. Particular emphasis should be placed on detecting the long period waves associated with surface waves and free oscillations. Inclusion of an active experiment utilizing explosion or impact generated signals to derive information about the sub-surface would be an important supplement to the seismic experiment.

D. Advanced Viking Seismic Instrumentation

An advanced Viking seismic instrument package should include the following capabilities which might be accomplished with either a single system or with multiple instruments.

(1) A short-period vertical component system for observation of short and middle frequency phenomena such as local Marsquakes volcanic activity and meteoritic impacts.

(2) A long-period or wide-band 3 component system for observation of periods in the range of 2 to 2000 seconds period from natural events.

(3) A high frequency vertical component system for registration of waves generated by explosion of grenades deployed in a linear array for a shallow refraction determination of the sub-surface.

(4) A system for detection and rejection of lander induced noises.

The capability of recording simultaneously all period pass bands with selectable transmission of data would be desirable.

In the interest of reliability and back-up, and if weight, volume, and power constraints permit, it would be well to have separate seismometers for the long-period and short-period systems as well as individual electronic filtering systems for the various pass bands.

Very wide-band recording with subsequent playback filtering to extract the spectrum of interest can be used instead of the various peaked bands shown only if the data system has a dynamic range great enough to give the required sensitivity at the ground periods of interest without over-loading on noise of other periods. For very high magnification, such as is required in the short period pass bands, this is usually not feasible.

It is imperative that the advanced Viking seismometers be emplaced on the Martian surface as far as possible from the lander. They must be protected from large or rapid temperature changes, and from the forces of wind. A covering such as that used to protect the Apollo lunar instrument, but not in contact with the instruments, would be appropriate.

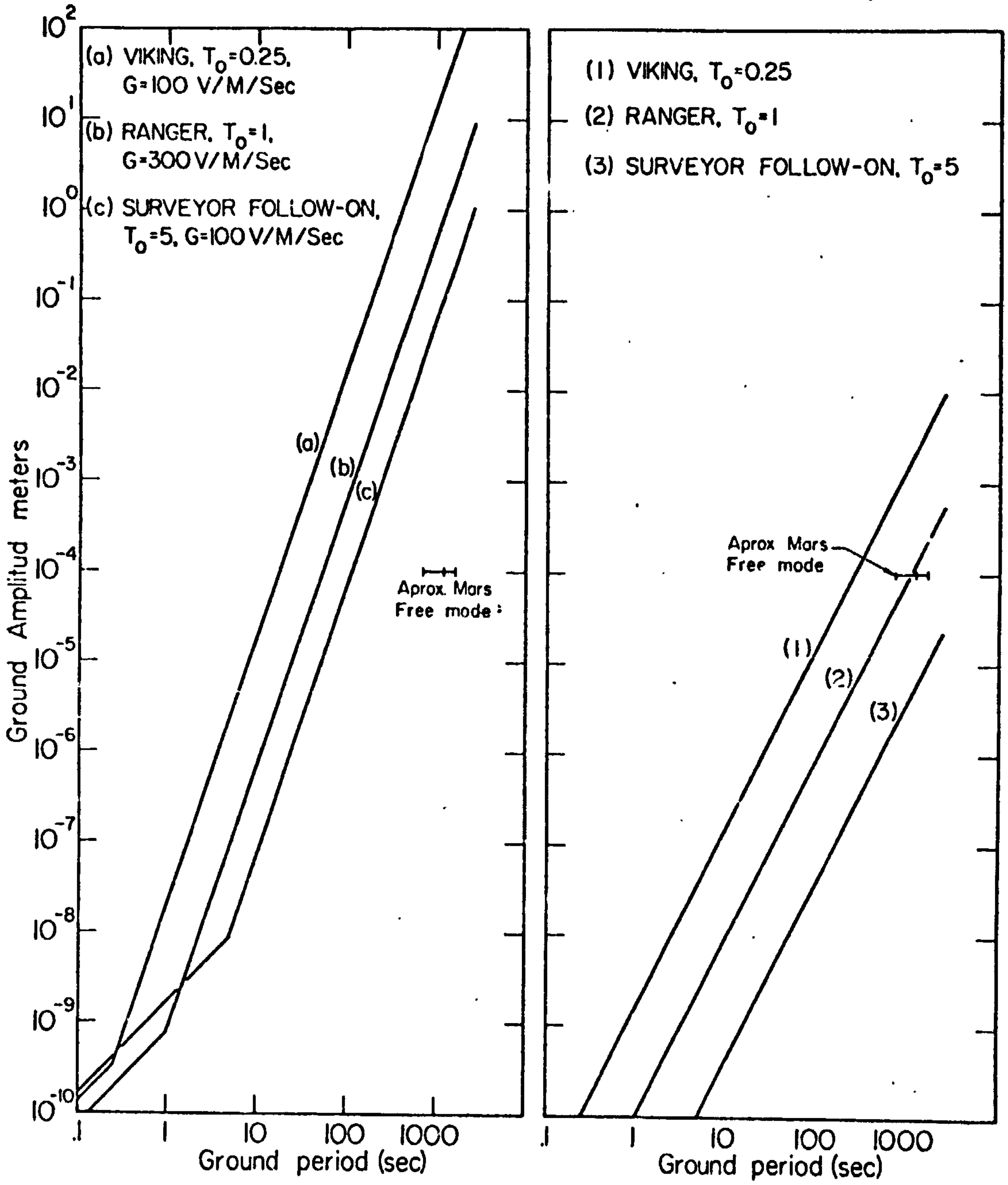
Emplacement of multi-station arrays would aid greatly in location of seismic areas on the planet. Considerable work has been done by various groups in the application of penetrometers dropped from an orbiter (Ref for emplacement of instrument stations. This technique appears to be y of consideration for dispersement of arrays of seismic stations, each unit of which would telemeter data to a receiving center, perhaps the orbiter.

A number of discussions with groups conducting penetrometer studies indicate that seismic equipment similar in nature to the Ranger and Viking systems could survive the deceleration levels, temperatures, etc., associated with penetrometer drops. It has been learned that decelerations of less than several thousand G were typical in tests; the Ranger instrumentation (Ref. 3, 4) specification was 3000 G, in tests it survived 7000 G. The Viking package has in tests survived short duration 2500 G impulses from the firing of pyrotechnic devices aboard the spacecraft.

Because of the 1-15 meter depths to which they come to rest, penetrometer emplacement has advantages in coupling of the instruments to the seismic signals, isolation from wind and surface noise, and in temperature stabilization, and should be considered particularly for missions where arrays of stations are desired.

Figure 1 shows the relative behavior of the Viking, Ranger, and a Surveyor follow-on device of longer period, previously developed by Caltech, in the reception of long period waves including free mode oscillations. It is estimated (Dr. Hiroo Kanamori) that a large Marsquake might generate free mode amplitudes of the order of 0.1 mm. It can be seen from these curves that free modes could be detected by 1 second (or longer) period instruments fitted with displacement transducers of ordinary capabilities. More sophisticated techniques might extend the detection capability to shorter period and more rugged instruments. Actually, the displacement transducer utilized on the 5 sec instrument indicated has about 5 times the resolution capability of the 'standard' assumed for this comparison (Ref. 5).

Following are some instrumental characteristics and parameters which are suitable for an advanced Mars seismic experiment but which are not intended to be specifications for such instrumentation. Some methods which can be used in achievement of the goals are discussed. Final selection of characteristics will be influenced by Viking '76 data, but much can be done in the way of preliminary planning.



COMPARISON OF SEISMOMETER SENSITIVITIES VS GROUND PERIOD

FIGURE 1.

E. Active Experiment Instrumentation

Caltech has previously developed a system of deployment of explosive grenades for performing an "active" seismic experiment. This was the original work on which the Apollo active experiment hardware was based (Ref. 6). The hardware consisted of a mortar package for deployment of the grenades, and included ranging and explosion timing devices. Similar techniques might be considered for future Viking missions.

Also suggested as a method of explosion deployment is the use of a penetrometer-grenade, perhaps dropped within an array of seismic sensor penetrometers, it is visualized that near the termination of a mission the grenade penetrometer (which might previously have had other functions) would transmit a radio signal detectable at the central receiving station previously mentioned, and terminated by the explosion of the charge as an indication of the seismic signal origin time.

II. Seismic Instrument Characteristics

A. Long-Period

Peak in sensitivity to ground displacement at several ground periods and fall off symmetrically on either side of peak. The response should be extended to as long a period as is consistent with the state of the art, up to 2000 seconds (see Figure 2).

B. Wide-Band

Flat displacement response over various band widths up to 500 seconds ground period (see Figure 2).

C. Short-Period

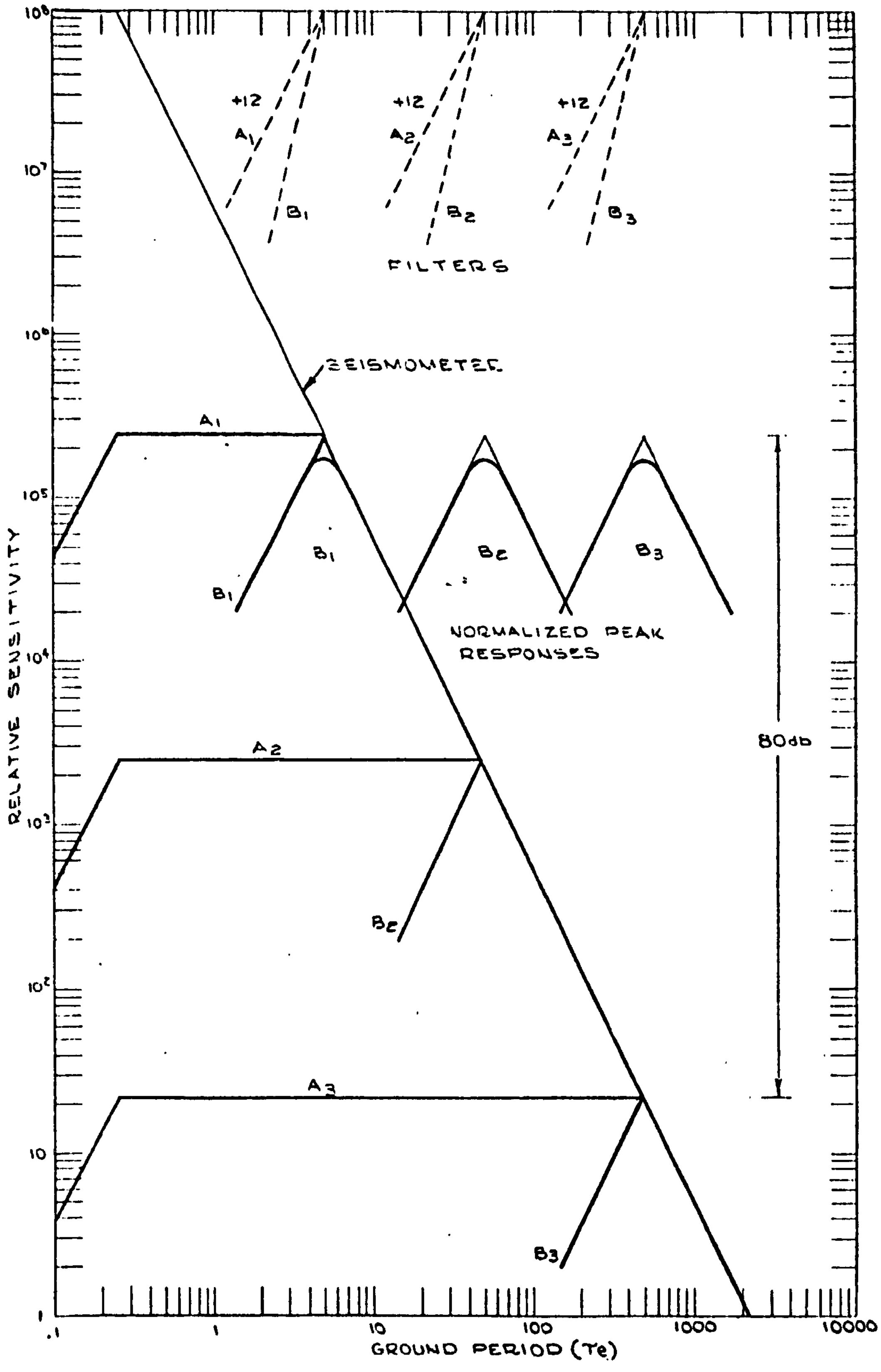
Response similar to Viking '76 but with added high frequency capability for performance of an 'active' experiment (Figure 3).

The same short period seismometer could be used for natural events and explosions with switchable filtering.

D. Ground Motion Resolution (typical)

(1) Long-period (peaked) -- 10^{-5} mm at 50 seconds ground period.

(2) Wide-band -- 10^{-4} mm at 100 seconds ground period.



SUGGESTED INSTRUMENT RESPONSE CURVES

FIGURE 2

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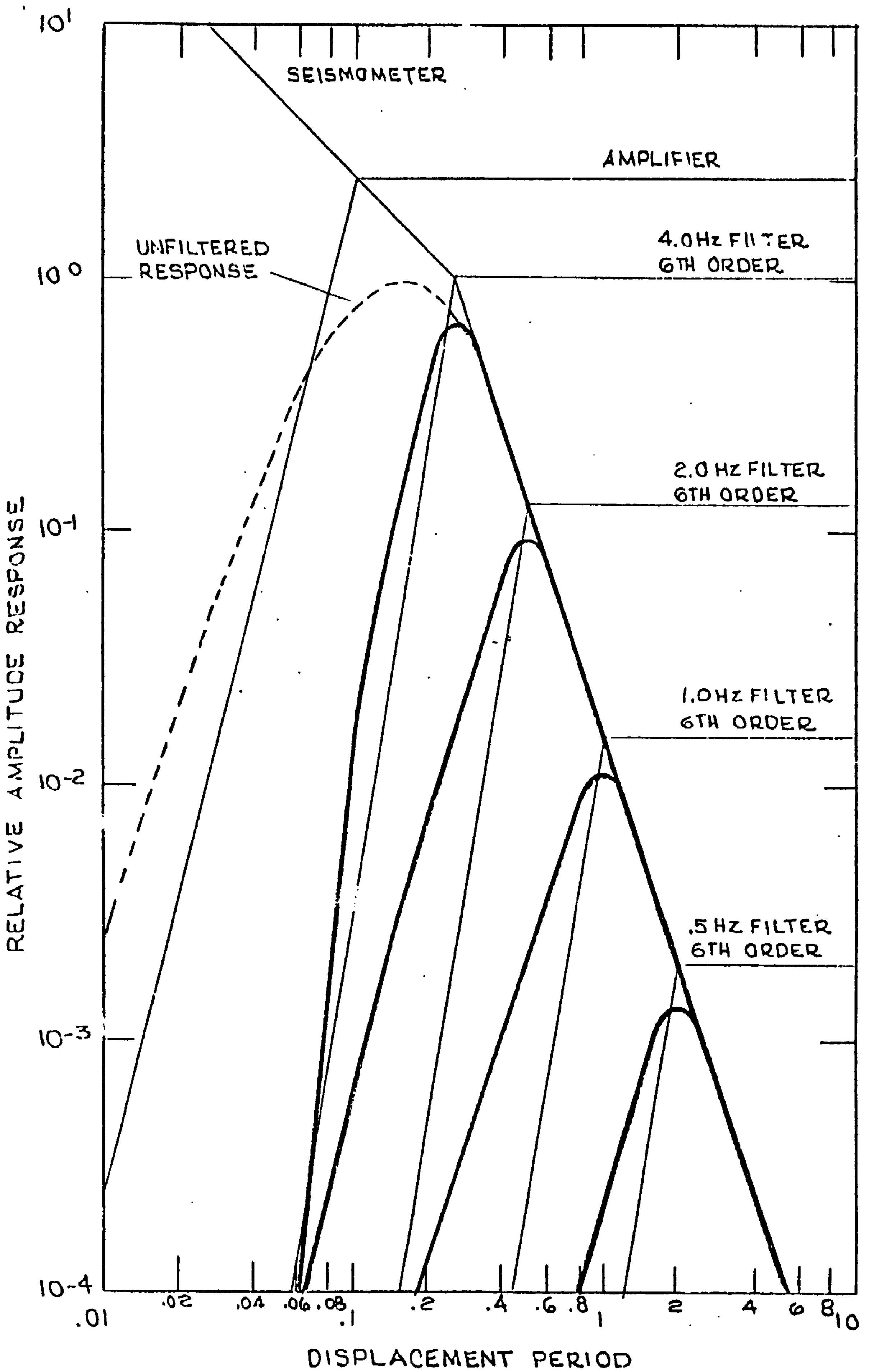


VIKING SYSTEM RESPONSE FIGURE 3

(3) Short-period

(a) Passive experiment -- 10^{-6} mm @ 0.2 seconds.

(b) Active experiment -- 10^{-8} mm @ 104 seconds.

In general, the suggested short-period instrumentation resembles characteristics of the Ranger, Surveyor, Apollo or Viking with extensions and modifications made possible by new techniques. Sensitivities of the three systems are shown in Figure 4.

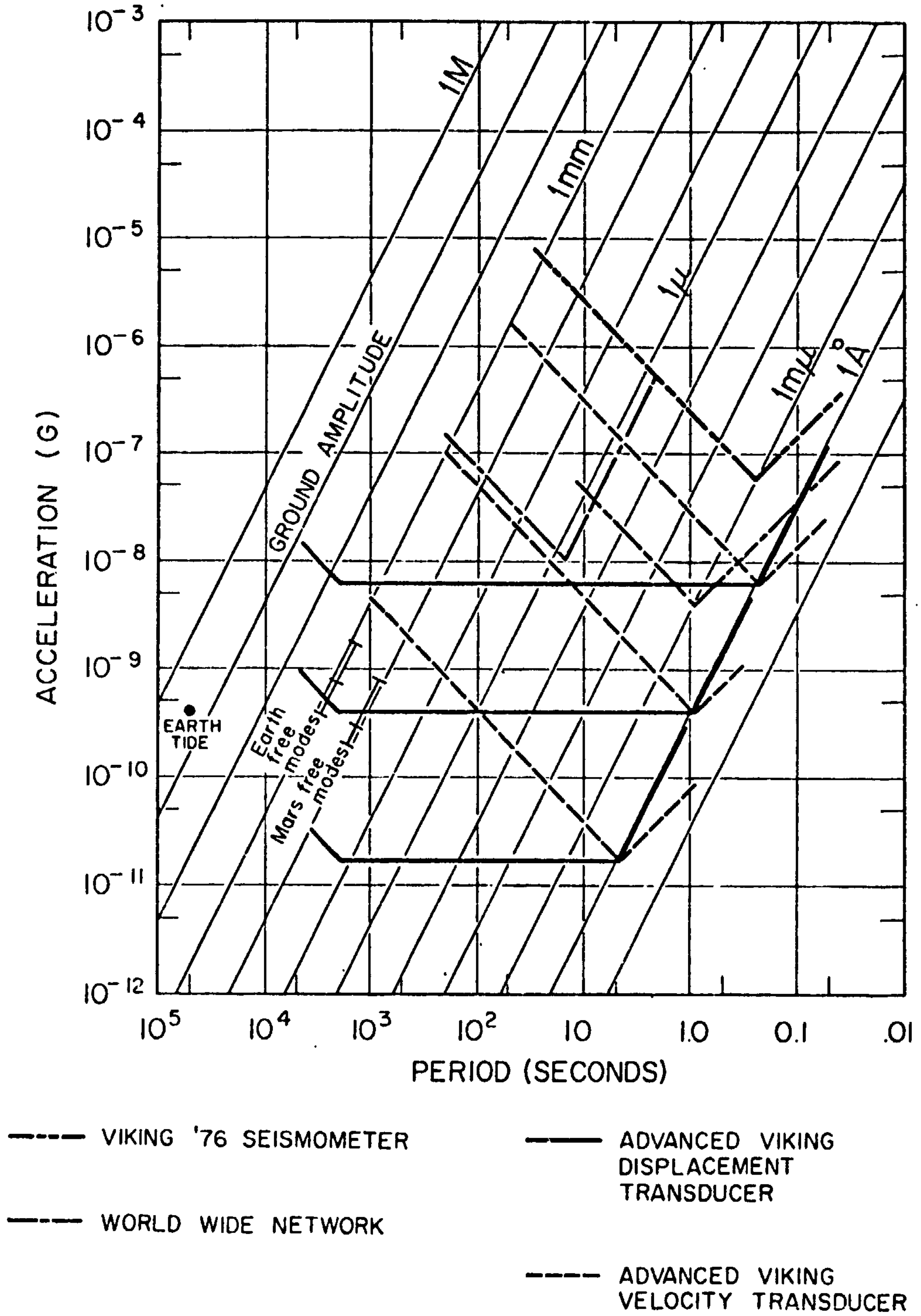
III. Implementation

Discussion of instruments to survive the various launch, flight, and landing conditions and the Mars surface environment and having suitable response characteristics have been discussed in previous reports. Seismometers and transducers exist which, in combination with today's electronic processing and filtering capabilities, are applicable to the mission; only brief comments are made herein concerning sensors. The bulk of this discussion is related to signal conditioning and computer techniques which will make the accumulation of more data possible, and provide processing which will result in more efficient transmission to earth.

A. Sensors

Two sensor developments of interest are:

(1) In a series of tests recently conducted by Martin-Marietta on a caged Diax quartz suspension bore-hole accelerometer, it was determined that (after several failures) this instrument could survive the various vibration and shock tests specified for Viking instruments. The MM report indicated that major reconfiguration of the instrument would be required



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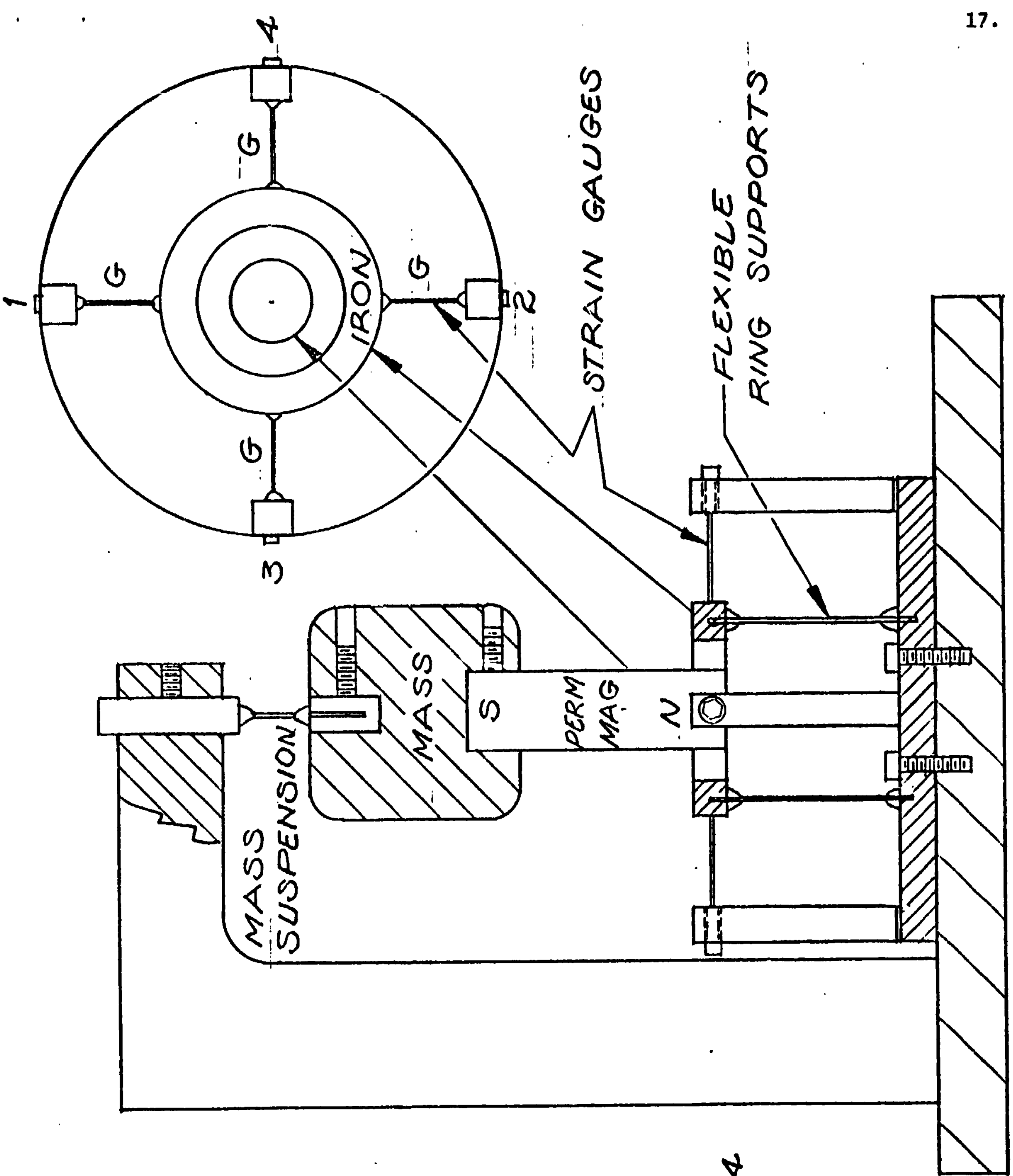
SENSITIVITIES OF SEISMIC SYSTEMS *FIGURE 4.*

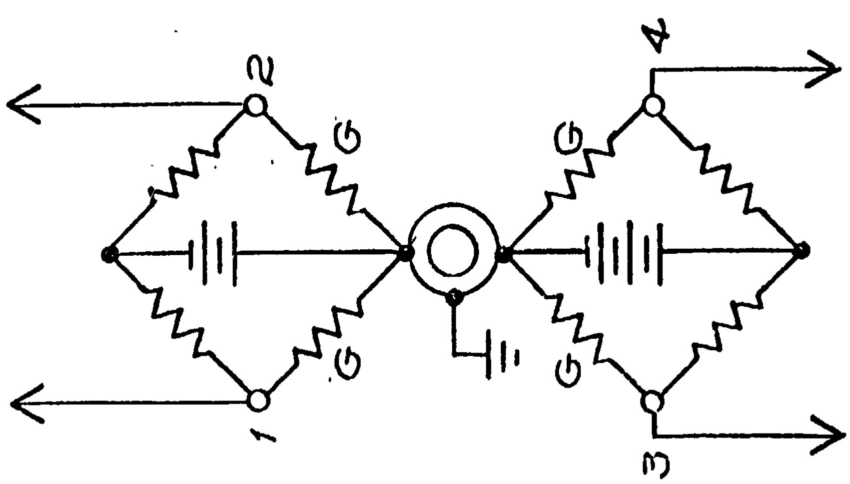
for Viking use, but that this was feasible. This instrument should be considered in future instrument selection (Ref. 7).

(2) Previously, Caltech has modeled an instrument using silicon strain gages as output transducers, in contrast to the magnet-coil velocity type, or the variable capacity or differential transformer displacement types commonly used. A unique coupling of the mass to the gages gives an output proportioned to the mass displacement. This device was arranged to give outputs for two horizontal components of motion from a single suspended mass; it appears that addition of a vertical component is not out of the question.

This seismometer, shown schematically in Fig. 5, consisted of a mass suspended by a single wire support so that it was free to respond in any direction in the horizontal plane. Projecting from the bottom of the mass was a rod magnet which extended into an iron ring spaced radially by about 1 cm and flexibl mounted from the instrument base. The ring was restrained radially to the base with four silicon strain gages separated by 90°. The pairs 180° apart were connected into two separate bridge circuits.

The initial period of the pendulum was 0.3 seconds; this was extended to 1.0 second by the attractive force between the iron ring and the magnet. Thus approximately 90% of any mass displacing force is applied to the gages, since the restoring force cancellation provided by the magnet and ring will vary as the square of the period extension ratio.





SCHEMATIC OF CALTECH EXPERIMENTAL SEISMOMETER FIGURE 5.

Either AC or DC excitation can be used on the gages; use of AC makes possible the employment of synchronous detection (lock-in amplifier) techniques to improve the signal to noise ratio.

Recent development of a high-sensitivity piezo-resistive CdS thin-film strain gage was reported (Ref. 8) which might be applied to the device described above.

From Fig. 1 it is seen that free modes of oscillation of Mars can probably be observed with seismometers having periods as short as 1 second and fitted with displacement transducers. Longer period devices, perhaps 5 seconds, would enhance the possibility of observing such phenomena.

Seismometers utilizing displacement transducers must be zero-servoed. In those for detection of shorter period data, direct inverse feedback to the pendulum via a feed-back filter of τ much greater than the data period is feasible and coventional.

In instruments for detection of 2000 sec ground periods, ordinary feedback filtering becomes excessively cumbersome and other approaches such as a fine grained mechanical incremental servo (an extension of the techniques described in Ref. 5) or new techniques described in the following pages may be applicable to instrumentation for future Mars missions.

B. Seismometer Servo and Data Handling

Fig. 1 compares the output signals obtained by seismometers fitted with velocity and displacement transducers. A velocity transducer is often simply a coil attached to the inertial mass and immersed in a magnetic field created by a magnet fixed to the frame of the instrument. Relative motion between the frame and mass generates a voltage. The transducer is simple, passive, rugged and relatively insensitive to the centering and tilt of the instrument. The response to ground period with this arrangement, however, decreases by 60 db/decade with increasing ground period.

A displacement transducer will improve the long period response by 20 db/decade. Thus, at 2000 sec, an instrument of 5 sec natural period fitted with a displacement transducer will have an output signal 400 times that of a similar instrument fitted with a velocity transducer (signals normalized to the natural period of the instrument) and a 0.25 sec instrument with a displacement transducer, 8000 times that of one fitted with a velocity transducer. Displacement transducers, however, are usually active, more complicated to design and construct and are sensitive to zero drift of the pendulum and tilt of the instrument.

To reduce the sensitivity to tilt and centering it is common practice to use a form of negative feedback between the frame of the instrument and its suspended mass which produces an apparent increase in the natural frequency of the seismometer. Because the tilt sensitivity is proportional to the square of the natural frequency of the instrument, a reduction in the apparent natural frequency by a factor of 10, for example, will reduce the tilt sensitivity of the displacement transducer by a factor of 100.

However, to maintain the desired response to frequencies of less than the natural frequency of the seismometer, filtering is used in the feedback to avoid degenerative feedback of the desired information. The form of this filtering for earth and lunar experiments to date has been that of a first order filter having a time constant long compared to the longest desired data period in the feedback loop. Such a filter has the effect of changing the normal 20 db/decade roll off of the seismic response to a 60 db/decade roll off, and although perceptive design can maintain adequate sensitivity in the vicinity of the instrument period, without an impossibly cumbersome filter, signals of the period of the free modes of Mars would be greatly attenuated.

To incorporate negative feedback but also maintain the 40 db/decade response of the displacement transducer requires a second order filter in the feedback loop. Fig. 6 is a Bode plot comparing the response of a system using a first order filter vs a second order filter to produce the same reduction in tilt sensitivity (a factor of 100). For a 5 sec seismometer, the signal at 1400 seconds with second order filtering produces an output 32 db or a factor of 40 times greater than the same seismometer using feedback with first order filtering.

Figure 7 shows the block diagram and transfer function of the feedback system with the second order filter in the feedback loop. The relationship between the undamped natural period of the seismometer, ω_n, the apparent natural period or tilt response, ω_o, the cutoff frequency of the low-pass filter ω_F, and the desired breakpoint of the low frequency fresponse ω_a, is given. Thus for a 5 sec ($\omega_n = 1.26$) natural period and a response which breaks at 2000 sec ($\omega_a = 3 \times 10^{-3}$), a feedback filter at 20,000 sec ($\omega_F = 3 \times 15^{-4}$) will produce an apparent 0.5 sec instrument ($\omega_o = 12.6$).

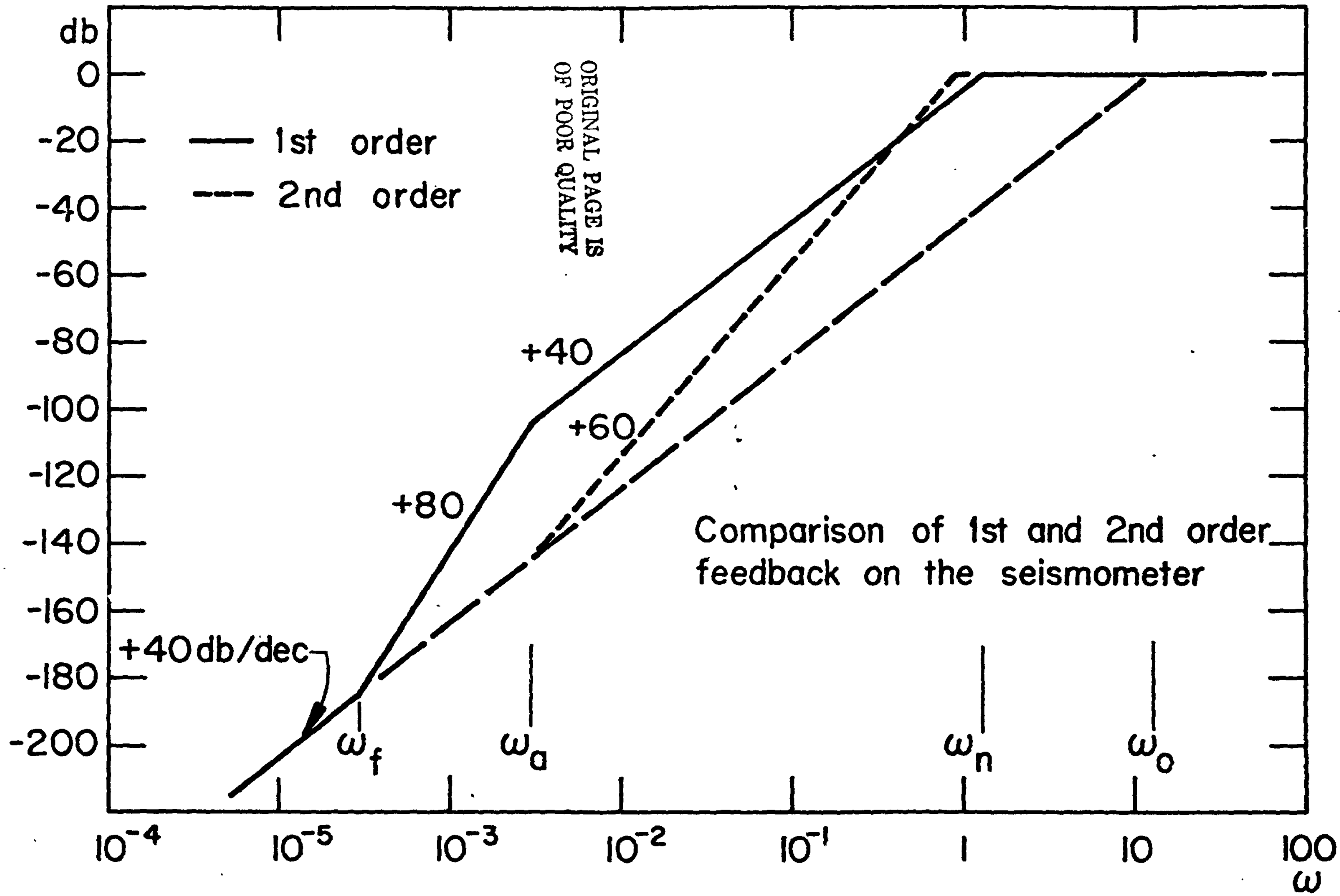
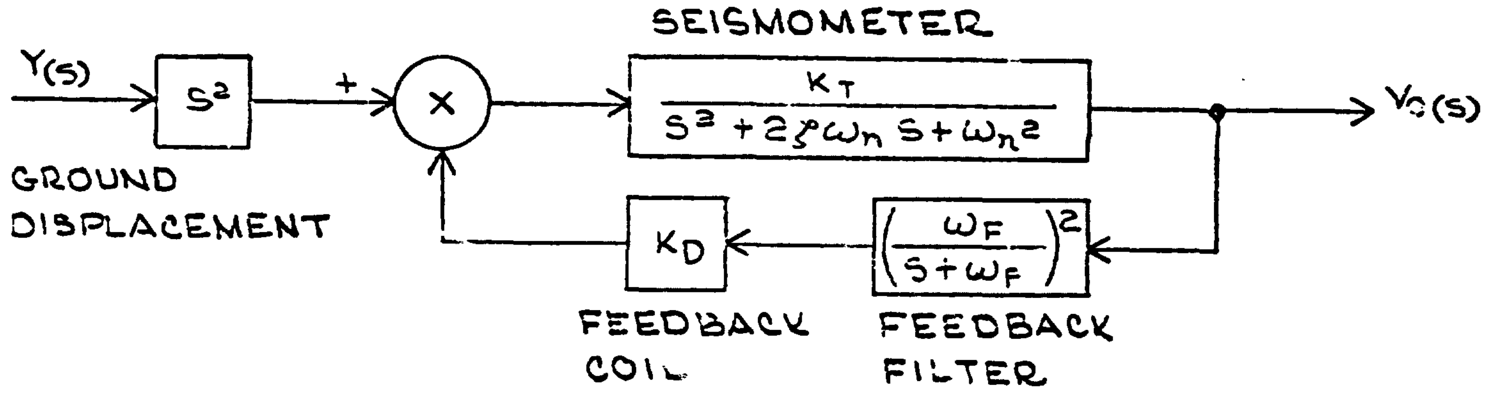

db
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
1st order
2nd order
+40
+60
+80
+40db/dec
ω_f
ω_a
ω_n
ω_o
10^{-4}
10^{-5}
10^{-3}
10^{-2}
10^{-1}
1
10
100
ω
Comparison of 1st and 2nd order feedback on the seismometer

FIGURE 6



TRANSFER FUNCTION

$$\frac{V_o}{Y}(S) \approx \frac{K_T (S+\omega_F)^2 S^2}{S^4 + 2\zeta\omega_n S^3 + \omega_n^2 S^2 + 2\omega_F \omega_n^2 S + \omega_F (K_D K_T + \omega_n^2)}$$

FACTORED

$$\frac{V_o}{Y}(S) \approx \frac{K_T (S+\omega_F)^2 S^2}{(S^2 + 2\zeta\omega_n S + \omega_n^2)(S+\omega_a)^2}$$

S = COMPLEX VARIABLE $(\alpha + j\omega)$

K_T = TRANSDUCER GAIN

$$\omega_a = \frac{\omega_F \omega_o}{\omega_n}$$

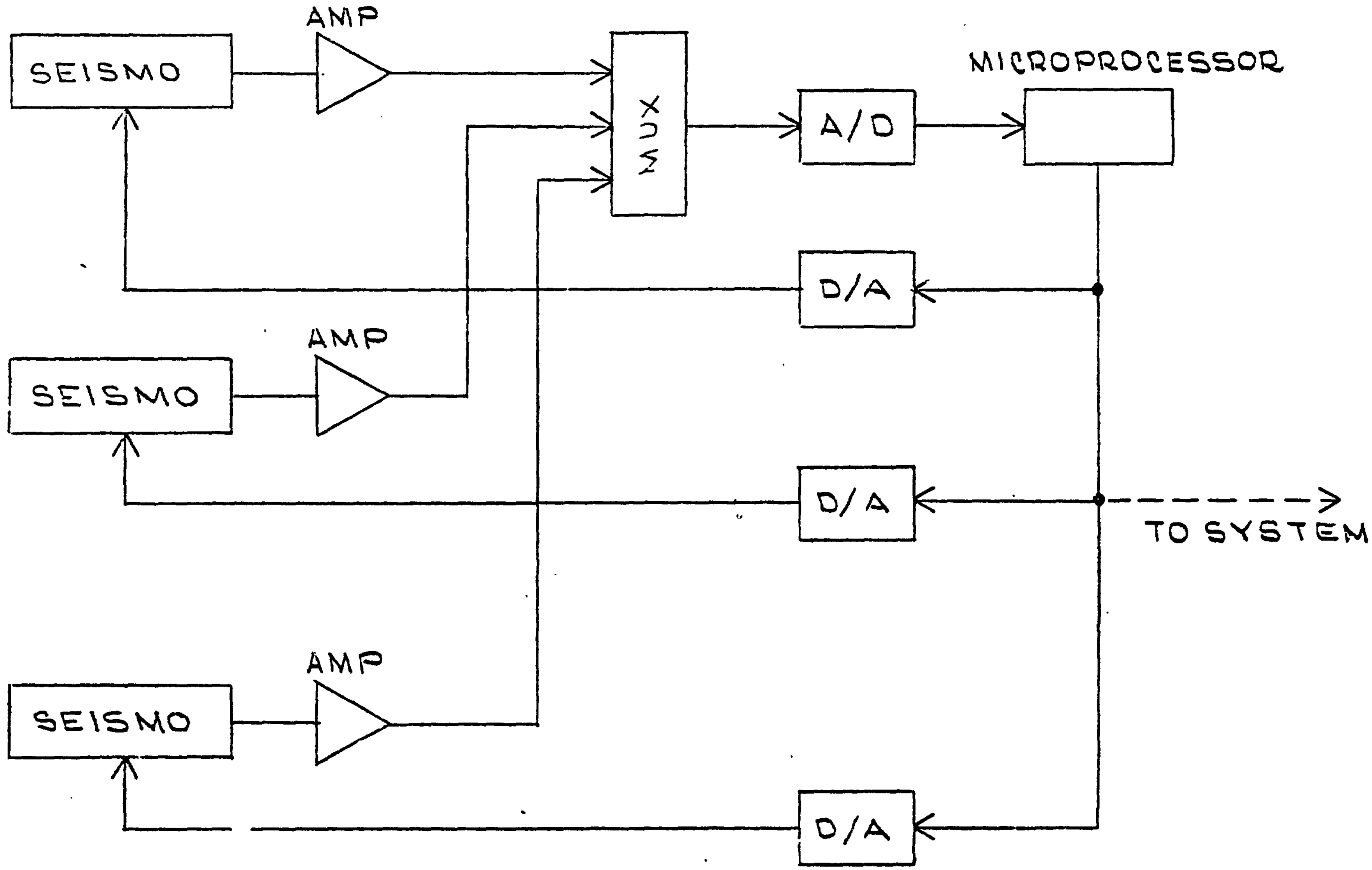
BLOCK DIAGRAM - FEEDBACK STABILIZED SEISMOMETER

FIGURE 7

This will reduce the sensitivity to centering and tilt by 100 times.

To produce a second order filter with a cutoff frequency of 3×10^{-4} radians/sec (greater than 5 1/2 hr. cutoff period) is not practical using normal analog techniques. Even with active circuitry the component size would be large and the noise and drift of the circuitry might well nullify the reduction in tilt sensitivity gained using negative feedback. For this reason this report discusses the use of a monolythic digital microprocessor in the feedback loop. The microprocessor would create the desired filter response by arithmetic operations on the seismic data.

Fig. 8 is a block diagram showing a single microprocessor controlling three mutually orthogonal seismometers. The seismic signal is amplified, multiplexed and converted to a digital representation by an analog-digital converter. The microprocessor then filters the data using conventional digital filtering techniques and outputs the data to a digital-to-analog converter for each axis. The analog signal from each D/A converter is directed to a magnet and coil arrangement such that a force is produced between the frame and inertial mass of the seismometer. The phasing of the force (negative feedback) is such as to raise the natural frequency of the seismometer except for those frequencies between ω_a and ω_o'; (Fig. 6) where the effect of the feedback is removed due to the filtering in the feedback loop. The microprocesssor would also pass the data along, after perhaps some additional filtering, scaling or other preconditioning discussed elsewhere in this report, to the rest of the system for additional arithmetic operations, formating and storage.



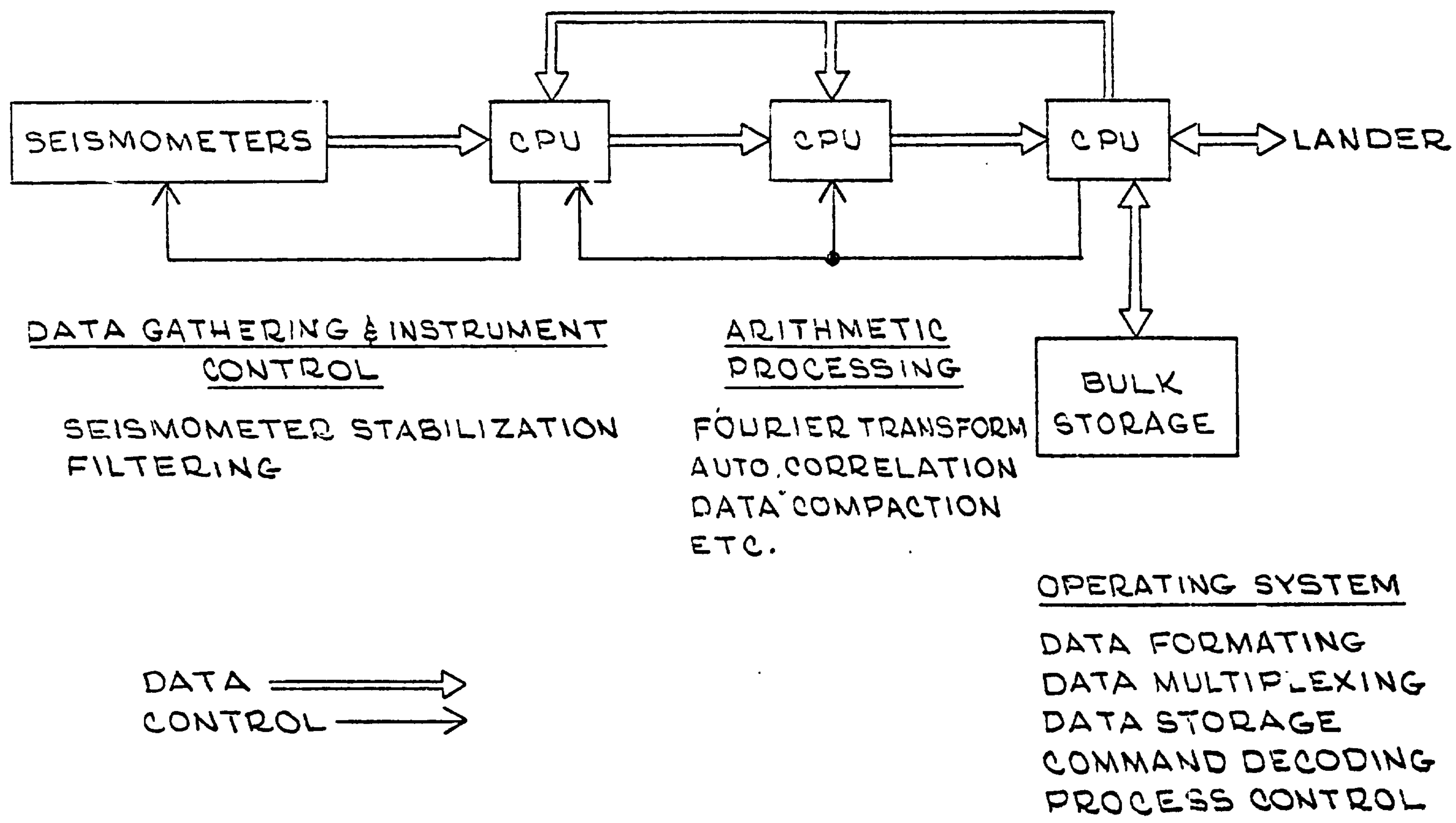
THREE AXIS, FEEDBACK STABILIZED SEISMIC SYSTEM

FIGURE 8

Ref. 1 is a report based on work in 1971 and early 1972 on performance criteria for a Post Viking '76 Martian seismic experiment. In this report we made what we thought at the time to be a bold proposal when we suggested that a general purpose computer be dedicated to the seismic experiment. The reasoning was that there would be a savings in hardware and power consumption with a large increase in experimental flexibility compared to the custom LSI electronics used in the Viking '76 design. Although the use of a general purpose computer to control an experiment was and is not uncommon in the laboratory, a substantial argument was felt necessary to justify this approach for a remotely controlled planetary experiment. As of this writing, however, the wide acceptance of the monolythic CPU in everyday items such as calculators, point-of-sale terminals, household appliances and toys would indicate that no argument is needed to justify the inclusion of one or more general purpose computers in a planetary seismic experiment.

A simplified block diagram of a seismic experiment built around three general purpose monolythic microcomputers is shown in Fig. 9. Three computers are shown because of the straightforward way the system may be partitioned into the three functions of (a) operating system (software support of all experimental operations), (b) arithmetic processing, and (c) instrument control. However, further study may show that some of these functions might be combined into a single CPU or alternately perhaps another CPU might be added to perform a single arithmetic operation such as the computation of the fast Fourier tranform. There are a number of reasons for the use of several CPU's as opposed to a single microprocessor to controlling all operations.

First, although present microcomputers have all the capabilities of



BLOCK DIAGRAM—SEISMIC EXPERIMENT

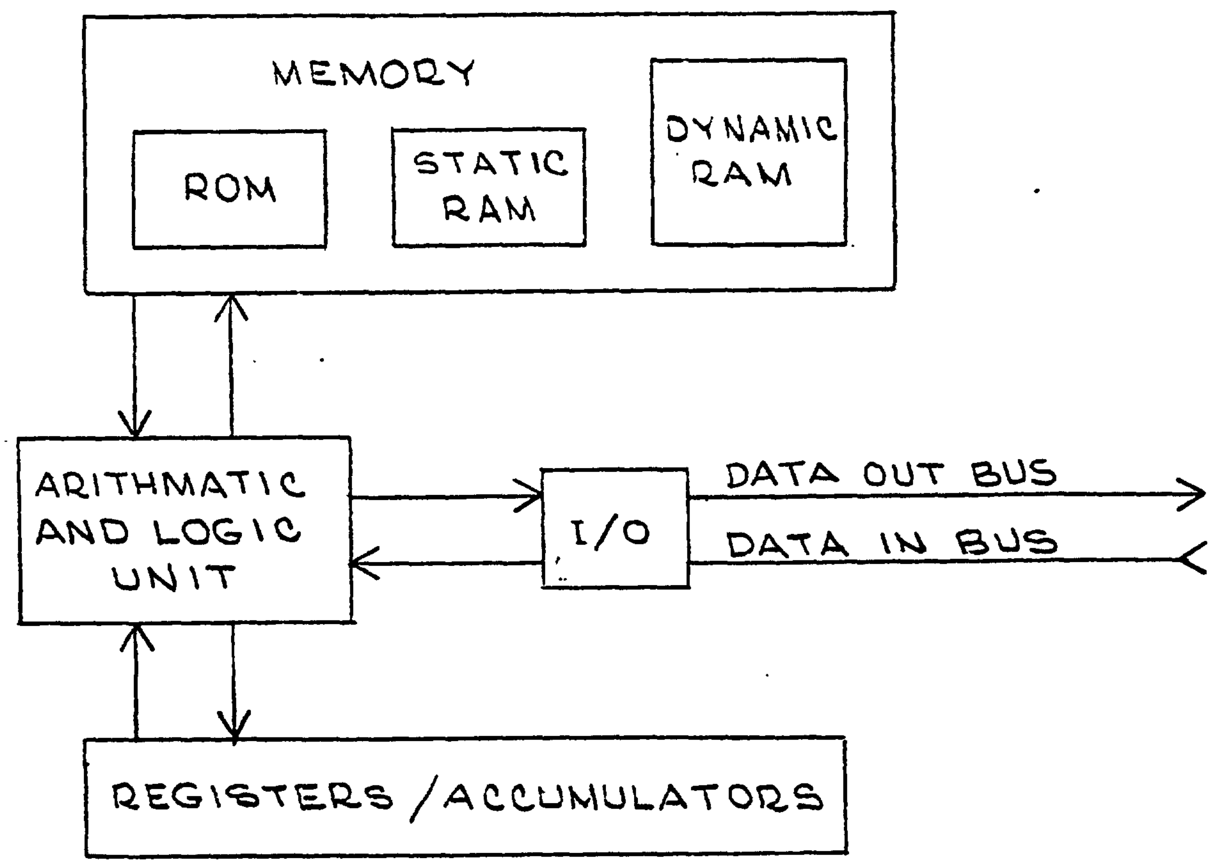
FIGURE 9

modern minicomputers, at the present they are slower. Microcomputer cycle times are in the 1 to 10 microsecond range whereas the minicomputer cycle times are 0.5 to 1.5 microseconds. There are indications, however, that before the year is out the speed of the microcomputers will approach that of the fastest minicomputers.

Second, as already mentioned, the functions of real time operating systems, arithmetic operations, and instrument control, represent three distinct and separate software development efforts. The interaction between these functions can be smoothed if it is kept at the level of data interface and control. For instance, the software development associated with the control of the seismometers would probably proceed along with the development of the seismometer and its analog electronics. The operating system must be compatible with the requirements of the lander as well as the seismic experiment. The arithmetic operations, on the other hand, are dependent of the mechanics of data gathering, mass storage and transmission. By keeping the preceding functions separated, software development may proceed independently of one another and changes in one area would have minimal effect on other areas. The microprocessors envisioned in this design would resemble the present minicomputers. In fact, the approach of several microprocessor manufacturers is to emulate popular minicomputers. Thus, the software development for the seismic experiment could be performed and tested with readily available systems.

Due to the proliferation of monolythic CPU's (there were a half dozen new manufacturers and more than a dozen new products introduced in 1974) this discussion is not based on any single product or technical design, but rather on a mythical CPU which has, more or less, all the characteristics which are desirable for controlling a seismic experiment. It is anticipated that continued refinement and development will produce a product similar to that outlined. In fact, a CPU which is built around a microprogrammed logic structure may be individually tailored to optimize its application. Thus in a multiple CPU concept, the same monolythic hardware can be optimized for each of the individual functions (operating system, I/O, instrument control, arithmetic processing, etc.). There are presently on the market or in development several monolythic CPU's which might be incorporated into the following concept.

A block diagram of the general purpose microprocessor is shown in Fig. 10. The only unique feature of this CPU is the use of a read only memory (ROM) and two forms of random access memory (RAM). The ROM would contain all of the software routines, written in pure procedure form, which that particular CPU would use. The static RAM would contain the coefficients for use with the software routines. Thus, the routines in the ROM are fixed but the coefficients may be changed by transmission from earth. The dynamic RAM would be used for large volume data storage and buffering in the manner of a disk or drum bulk storage device. 2.5×10^5 to 10^6 bits of storage would not require unreasonable power or volume using present available dynamic charge-coupled device serial memories.



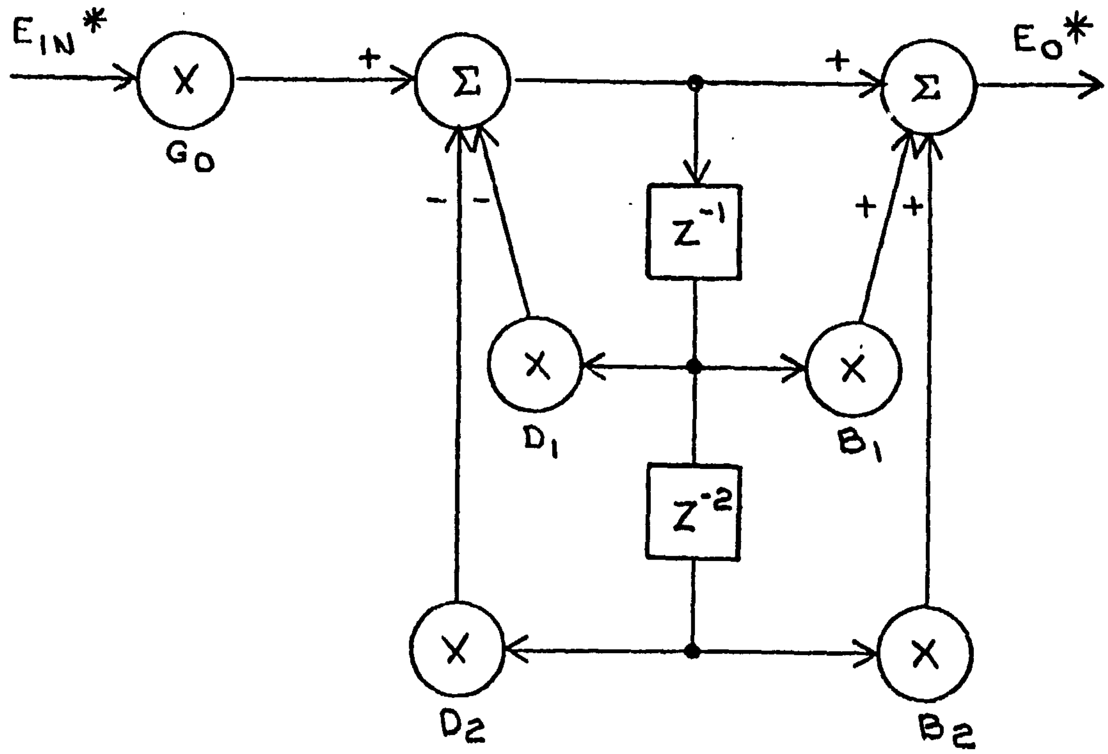
GENERAL PURPOSE MICROPROCESSOR

FIGURE 10

Consider the CPU in Fig. 9 dedicated to data gathering and instrument control. Fig. 8 shows this function in more detail. The signal from each seismometer is amplified, multiplexed, digitized and presented to the microprocessor. The microprocessor will do the formating of the data and perhaps such operations as filtering prior to passing the data on for arithmetic processing or bulk storage. However, the prime function of this CPU is to operate in a closed loop, with the seismometer, controlling the response of the instrument.

As was previously discussed in this report, the requirement to record the free modes of Mars dictates the use of a displacement transducer on the seismometer. This means that the instrument will be sensitive to tilt and drift of the seismic mass. This sensitivity varies in direct proportion to the square of the natural period of the seismometer. Through the use of negative feedback it is possible to produce an apparent short natural period to signals produced by tilt and drift while maintaining the desired response to seismic signals.

For this application the microprocessor will produce the proper feedback signals by scaling and filtering the seismic data. The filter is a second order digital filter for which the logic state diagram is shown in Fig. 11. The CPU then will output the data to a digital-to-analog converter (monolythic or a simple resistor ladder network). The analog signal is then directed to a coil which produces a force between the inertial mass and the frame of the seismometer. The overall response will be as shown in Fig. 12. This figure also shows how either the scaling or filter coefficients may be changed to change the total instrument response.



FILTER RESPONSE

$$\left(\frac{\omega_F}{S+\omega_F}\right)^2 = \left(\frac{\omega_F{}^2}{S^2+2\omega_F S+\omega_F{}^2}\right)$$

$$G_0 = \frac{\omega^2}{\omega^2+2\zeta\omega+1}$$

$$D_1 = 2(\omega^2-1)\,G_0$$

$$D_2 = (1-2\zeta\omega+\omega^2)\,G_0$$

$$B_1 = +2$$

$$B_2 = +1$$

$(\times)$ = PRODUCT

(Σ) = SUM

Z^{-1} = UNIT DELAY OPERATOR

$*$ = SAMPLED DATA

SECOND ORDER, LOW PASS, RECURSIVE DIGITAL FILTER

FIGURE 11

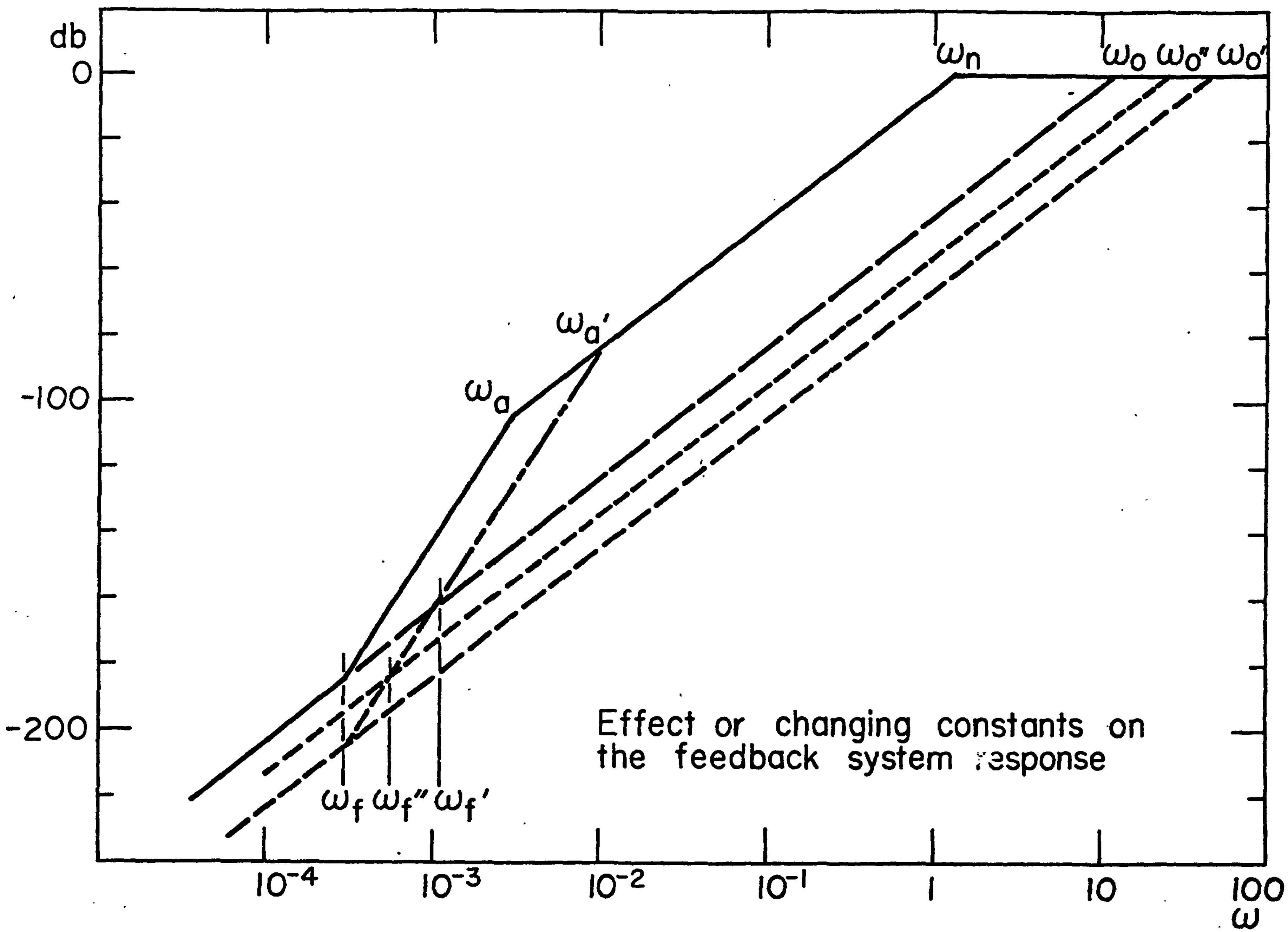

db
0
-100
-200
ω_n
ω_o ω_o'' ω_o'
ω_a'
ω_a
ω_f ω_f'' ω_f'
Effect or changing constants on the feedback system response
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
100
ω

FIGURE 12

That is, the corner break frequency ω_a, might be shifted to ω_a' by either shifting ω_F to ω_F', a change in filter coefficient, or by a change in the total loop gain (scaling) to produce a new ω_o, shown as ω_o'. Or a combination of changing scaling and filter coefficients, shown as ω_F'' and ω_F'' in the Figure, may be used to produce the desired ω_a' break point.

The logic state diagram shown in Fig. 11 is a recursive form of digital filter which will synthesize a complex pole-pair. This is sufficient for the second order filter used in the seismometer feedback loop. However, this function when used iteratively, can generate any order of minimum-phase functions (low-pass, band-pass or high-pass functions with zeros only in the left half of the complex-frequency plane). The algorithm, written as a pure procedure subroutine, would be stored in the ROM, making it available to any number of other routines. Operations like band pass filtering to improve the dynamic range and comb filtering to obtain the spectral content of the microseismic activity may be accomplished with this one routine by simply changing the coefficients and iteration count. Note that the word size of the coefficients must be larger than the system word size (12 bits)* to reduce truncation error and to insure stability of the filter.

*This system will expand the dynamic range of 42 db used in Viking '76 to 66 db by use of a 12 bit analog-to-digital converter. With an analog signal range of plus and minus 10 volts this requires the resolution of the least significant bit to be 4.89 mV. The dynamic range of the amplifiers will be extended by operating at a correspondingly lower gain. For instance, a voltage gain of 6204 with the 12 bit A/D converter is equivalent to the gain of 10^5 with the 8 bit A/D converter used in Viking '76. With the lower gain, the amplifiers' low frequency response may be extended to 0 Hz (Viking '76 was limited to 0.1 Hz) without suffering from excessive low frequency drift and noise. The dynamic range may be extended still further by having the control system detect an overflow and institute a gain change subroutine.

The software for the CPU which controls the operating system could be organized in much the same way present minicomputer real-time systems are organized. The system would be under control of "JOB" commands in a JOB table contained in its static RAM. This table, however, could be updated from earth to change the operating modes. As with the CPU used with the seismic instruments, the permanent routines would reside in a ROM with coefficients for the routines in a static RAM. At the present ROM storage has higher density and is less power consuming than RAM storage which makes it desirable to put as many of the routines as possible in ROM. In addition, the reliability of the ROM is greater than RAM so that certainly all essential routines should be ROM resident.

The CPU used for arithmetic operations would perform such functions as fast Fourier transform, computation of the auto correlation function, data compaction, decimation, additional filtering, etc. These routines would not differ greatly from algorithms pesently used.

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